

UNIVERSITY OF MINNESOTA
AGRICULTURAL EXPERIMENT STATION


OBSERVATIONS ON THE
CLEAR-WINGED GRASSHOPPER
(*Camnula pellucida* Scudder)

J. R. PARKER

DIVISION OF ENTOMOLOGY AND ECONOMIC ZOOLOGY



UNIVERSITY FARM, ST. PAUL



Digitized by the Internet Archive
in 2012 with funding from
LYRASIS Members and Sloan Foundation

<http://archive.org/details/observationsofcl00park>

AGRICULTURAL EXPERIMENT STATION

ADMINISTRATIVE OFFICERS

W. C. COFFEY, M.S., Director

ANDREW BOSS, Vice-Director

F. W. PECK, M.S., Director of Agricultural Extension and Farmers' Institutes

C. G. SELVIG, M.A., Superintendent, Northwest Substation, Crookston

M. J. THOMPSON, M.S., Superintendent, Northeast Substation, Duluth

P. E. MILLER, M.Agr., Superintendent, West Central Substation, Morris

O. I. BERGH, B.S.Agr., Superintendent, North Central Substation, Grand Rapids

R. E. HODGSON, B.S. in Agr., Superintendent, Southeast Substation, Waseca

RAPHAEL ZON, Ph.D., Superintendent, Forest Experiment Station, Cloquet

F. E. HARALSON, Assistant Superintendent, Fruit Breeding Farm, Zumbra Heights
(P. O. Excelsior)

W. P. KIRKWOOD, M.A., Editor

ALICE McFEELY, Assistant Editor of Bulletins

HARRIET W. SEWALL, B.A., Librarian

T. J. HORTON, Photographer

R. A. GORTNER, Ph.D., Chief, Division of Agricultural Biochemistry

J. D. BLACK, Ph.D., Chief, Division of Agricultural Economics

ANDREW BOSS, Chief, Division of Agronomy and Farm Management

W. H. PETERS, M.Agr., Chief, Division of Animal Husbandry

FRANCIS JAGER, Chief, Division of Bee Culture

C. H. ECKLES, M.S., D.Sc., Chief, Division of Dairy Husbandry

W. A. RILEY, Ph.D., Chief, Division of Entomology and Economic Zoology

WILLIAM BOSS, Chief, Division of Farm Engineering

E. G. CHEYNEY, B.A., Chief, Division of Forestry

W. H. ALDERMAN, B.S.A., Chief, Division of Horticulture

E. M. FREEMAN, Ph.D., Chief, Division of Plant Pathology and Botany

A. C. SMITH, B.S., Chief, Division of Poultry Husbandry

F. J. ALWAY, Ph.D., Chief, Division of Soils

C. P. FITCH, M.D., D.V.M., Chief, Division of Veterinary Medicine

STAFF OF DIVISION OF ENTOMOLOGY AND ECONOMIC ZOOLOGY

WM. A. RILEY, Ph.D., Entomologist and Parasitologist

A. G. RUGGLES, M.A., Entomologist

F. L. WASHBURN, M.A., Economic Zoologist

R. N. CHAPMAN, Ph.D., Associate Entomologist, Stored Food Products Insect Investigations

ERICH HORLBOG, Ph.D., Assistant Entomologist in Charge of Collections

S. A. GRAHAM, Ph.D., Assistant Entomologist, Forest Insect Investigations

CLARENCE E. MICKEL, M.S., Assistant Entomologist, Extension

O. C. MCBRIDE, A.M., Research Assistant, Insecticidal Investigations

*J. R. PARKER, M.S., Research Assistant

A. L. STRAND, B.S., Research Assistant

G. M. STIRRETT, M.S., Assistant in Entomology

WALTER CARTER, M.S., Assistant in Entomology

C. B. PHILIP, B.S., Assistant in Parasitology

*Resigned April 1, 1924.

CONTENTS

	Page
Introduction	5
Experiments with poisoned bran mash.....	6
Methods of conducting experiments with poisoned bran mash baits..	6
Composition of grasshopper baits used in experiments.....	7
First series of grasshopper bait experiments.....	7
Various attractants used with and without molasses.....	7
Relative value of attractants used in first series of grasshopper bait experiments	8
Does molasses increase the effectiveness of grasshopper baits?....	17
Second series of grasshopper bait experiments.....	17
Various attractants used with and without salt.....	17
Relative value of attractants used in second series of grasshopper bait experiments	18
Does salt increase the effectiveness of grasshopper baits?.....	26
What is the best grasshopper bait for Minnesota?.....	27
Response to meteorological factors	28
Effects of temperature.....	28
Lower temperature limits of activity.....	29
Upper temperature limits of activity.....	30
Temperatures at which various activities take place.....	31
Temperatures at which maximum feeding at poisoned bran mash occurs	33
Importance of the temperature factor in conducting grasshopper bait tests	39
Effect of wind.....	40
Effect of moisture.....	40
Miscellaneous notes on seasonal history and habits.....	42
Seasonal history for 1923.....	42
Difference in habits under varied environment.....	42
Summary	43
Bibliography	44

ILLUSTRATIONS

	Page
Fig. 1. Temperature and feeding records for <i>Camnula pellucida</i> July 8, 1923	34
Fig. 2. Temperature and feeding records for <i>Camnula pellucida</i> July 9, 1923	35
Fig. 3. Temperature and feeding records for <i>Camnula pellucida</i> July 11, 1923	36
Fig. 4. Temperature and feeding records for <i>Camnula pellucida</i> July 12, 1923	37
Fig. 5. Temperature and feeding records for <i>Camnula pellucida</i> July 13, 1923	38
Fig. 6. Temperatures of boards and tins compared with air temperatures 2 inches above ground.....	40

OBSERVATIONS ON THE CLEAR-WINGED
GRASSHOPPER*(Cammula pellucida* Scudder)

By J. R. PARKER

INTRODUCTION

The clear-winged grasshopper (*Cammula pellucida* Scudder) is widely distributed throughout the entire northern United States and southern Canada. It becomes so abundant at times that it is generally looked upon as one of the three most destructive grasshoppers in North America. The author has observed this species for twelve years under the semi-arid conditions of Montana, and during the summer of 1923 was privileged to study it under the more humid conditions of northern Minnesota. This bulletin is largely a record of the Minnesota studies but also points out some differences in the habits of the species in the two environments.

The author wishes to express his appreciation to the Division of Entomology and Economic Zoology for having been given the opportunity to study *C. pellucida* in Minnesota, and especially wishes to acknowledge the assistance of A. G. Ruggles, who contributed equally with the writer in carrying out the grasshopper bait experiments. Acknowledgment should also be made to the Montana Experiment Station for reference to data gathered in that state.

Somes (1914)¹ has pointed out that *C. pellucida* in Minnesota is largely confined to the northern half of the state and that in the Iron Range counties it is the most common grasshopper found. A study of grasshopper outbreaks in Minnesota also shows that only in the northern counties has it ever been abundant enough seriously to injure crops. Consequently this area was looked upon as the most likely to furnish a suitable place for the study of this species in 1923.

A survey made early in June showed that it was more than usually abundant in Itasca, St. Louis, and Carleton counties, the most heavily infested area found being in Carlton County, near Harney. Here a camp was established and *C. pellucida* was observed at all hours of the day from June 27 to July 15 and for several days in August and November.

¹ Dates in parenthesis refer to titles in the list of literature cited at the end of the paper.

The studies undertaken separate rather naturally into three parts and will be reported under the following headings:

- I. Experiments with Poisoned Bran Mash
- II. Response to Meteorological Factors
- III. Miscellaneous Notes on Seasonal History and Habits.

I. EXPERIMENTS WITH POISONED BRAN MASH

Experimental and practical work in many states have demonstrated that the use of poisoned bran mash is the most effective method of grasshopper control known. But while there is general agreement as to the method, there still remain differences of opinion in regard to the ingredients which should be used in making poisoned bran mash. In Montana, the addition of salt and the substitution of amyl acetate for citrus fruits in the Kansas formula is recommended; in parts of Canada salt is the only ingredient used other than bran, arsenic, and water; in South Dakota molasses is the only material used in addition to the basic ingredients named.

These differences in the composition of poisoned bran mash were discussed at a conference of workers interested in grasshopper control at Winnipeg in April, 1923, and a committee was appointed which outlined a uniform set of experiments to be carried out by workers in the several states and Canadian provinces represented. The infestation of *C. pellucida* at Harney presented an opportunity to try out the series under Minnesota conditions and the baits and methods reported on in this paper are with a few exceptions those suggested by the conference at Winnipeg.

METHOD OF CONDUCTING EXPERIMENTS WITH POISONED BRAN MASH BAITS

The various baits to be tried out were scattered uniformly over the surface of new tin plates 8 inches in diameter and one inch deep. Shellacked or painted boards 12 inches square were recommended for this purpose by the Winnipeg conference, but after several days' trial were discarded for reasons discussed later.

The arrangement of the pans containing the baits was varied to suit the local distribution of grasshoppers, with the object always in mind of having each bait accessible to an equal number. If the distribution was uniform over a considerable area, the pans were arranged in a circle 6 feet in diameter, but if the grasshoppers were massed in rather narrow strips, as was frequently the case, the pans were placed in a row from 6 to 10 inches apart.

At ten-minute intervals counts were made of the grasshoppers actually feeding at each bait. Fresh bait was put on a second set of pans ten minutes before the end of every hour and the pans were placed in different order in a new location having as nearly as possible the same degree of infestation as the first. At the beginning of each hour counting was transferred to the fresh baits.

The work was carried on in a well sodded pasture in cut-over stump land where *C. pellucida* was extremely abundant. From June 27 to July 3 the grasshoppers were all in the nymphal stage and were more densely massed and less easily disturbed than after they had acquired wings. This to a large extent accounts for the much larger numbers reported feeding during this period.

An accurate record of meteorological conditions was kept during the period of each experiment. Temperature and relative humidity were recorded by a hygro-thermograph placed four feet above the ground and shaded by a canvas held two feet above the instrument by four uprights. This was also checked by hourly sling psychrometer readings made at the spots where the baits were located. Wind mileage was recorded by an anemometer and hourly observations were made on the conditions of the sky.

COMPOSITION OF GRASSHOPPER BAITS USED IN EXPERIMENTS

The basic ingredients of all baits were bran, crude arsenic, and water in the proportions of 100 pounds bran, 5 pounds crude arsenic, and 12 gallons water. The following materials were used as attractants: amyl acetate, propyl acetate, butyl acetate, synthetic apple flavoring, and lemons. The chemicals were all used at the same strength—3 fluid ounces to 100 pounds of bran. Lemons were used at the rate of 24 fruits to 100 pounds of bran. In the first series of tests the various attractants were used with and without cane molasses and in the second series the attractants plus molasses were used with and without salt. The proportions were 2 gallons of molasses and 5 pounds of salt, when used, to 100 pounds of bran.

FIRST SERIES OF GRASSHOPPER BAIT EXPERIMENTS

VARIOUS ATTRACTANTS USED WITH AND WITHOUT MOLASSES

In the first series of experiments it was desired to learn the relative value of the various attractants used and to determine whether the addition of molasses made the baits more effective. The following combinations were used:

Formula 1—Bran arsenic mash plus amyl acetate and molasses

"	2	"	"	"	"	amyl acetate
"	3	"	"	"	"	butyl acetate and molasses
"	4	"	"	"	"	butyl acetate
"	5	"	"	"	"	propyl acetate and molasses
"	6	"	"	"	"	propyl acetate
"	7	"	"	"	"	lemons and molasses
"	8	"	"	"	"	lemons
"	9	"	"	"	"	synthetic apple flavoring and molasses
"	10	"	"	"	"	synthetic apple flavoring

These baits were tried out at Harney on six days—June 29 to July 2 and July 8 and 9. During the first four days the grasshoppers were in advanced nymphal stages; during the last two days practically all were adults.

In order that other workers may intelligently interpret the results secured, they should have complete data for each hourly period of the experiment, therefore a series of tables, each showing full data for the various hours of a single day, has been prepared (Tables I–VI.)

RELATIVE VALUE OF ATTRACTANTS USED

The relative attractiveness of the different grasshopper baits was judged by three standards: The total number of grasshoppers feeding at each bait during the entire period of the experiment; the number of hourly periods that each bait ranked first in number of grasshoppers attracted; and a system of weighting based on the rank of all the different baits during each hour of the experiment. The last two were added in order to prevent too high a rating of any bait that might have attracted an unusually large number of grasshoppers during a single day or even a few hours but had been out-ranked by other baits during the rest of the experiment.

Using the first standard and referring to the summary of results found in Table VII, it is found that amyl acetate and molasses (formula 1) stands out as distinctly the best bait of the series, attracting 1713 grasshoppers and exceeding its nearest competitor by 424, or 30 per cent. Amyl acetate (formula 2) stands second with 1389, but is little better than propyl acetate and molasses (formula 5) or butyl acetate and molasses (formula 3) with 1349 and 1340, respectively. Lemons (formula 8), lemons and molasses (formula 7), butyl acetate (formula 4), and propyl acetate (formula 6) are nearly equal in the numbers of grasshoppers attracted. Apple flavoring and molasses (formula 9) and apple flavoring alone (formula 10) rank the lowest of the series.

TABLE I
GRASSHOPPER BAIT EXPERIMENTS—HARNEY, MINN., JUNE 29, 1923

Bait ingredients other than bran, arsenic, and water	Number of grasshoppers feeding at baits during each hour*										Total	Rank	
	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5			5-6
Amyl acetate and molasses.....								161	120	51	32	364	1
Amyl acetate								177	102	34	14	327	4
Butyl acetate and molasses.....								125	78	25	29	257	8
Butyl acetate								93	68	64	40	265	6
Propyl acetate and molasses								155	101	27	41	324	5
Propyl acetate								153	35	52	21	261	7
Lemons and molasses								165	93	54	23	335	3
Lemons								177	109	28	28	342	2
Apple flavoring and molasses.....								65	97	38	36	236	9
Apple flavoring								125	68	22	31	246	10
Total number feeding during each hour.....								1396	871	395	295		
Rank of each hour in relation to number feeding.....													
Hourly mean temperature								72	73	73	70		
Hourly mean relative humidity.....								57	45	45	52		
Sky (C = Clear; D = Overcast).....								C	C	C	C		

* Experiment started at 2 p.m.

TABLE II

GRASSHOPPER BAIT EXPERIMENTS—HARNEY, MINN., JUNE 30, 1923

Bait ingredients other than bran, arsenic, and water	Number of grasshoppers feeding at baits during each hour												Total	Rank
	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7		
Amyl acetate and molasses.....	18	63	140	28	20	21	24	53	17	22	14	..	420	1
Amyl acetate	12	58	71	8	14	19	19	25	20	28	13	..	287	3
Butyl acetate and molasses.....	14	30	76	25	11	22	37	17	5	17	12	..	266	5
Butyl acetate	7	23	56	22	10	15	7	6	24	20	10	..	200	10
Propyl acetate and molasses.....	4	23	105	12	15	11	14	22	20	27	14	..	267	4
Propyl acetate	12	100	66	25	7	22	12	10	16	7	16	..	293	2
Lemons and molasses.....	14	55	35	23	16	22	14	22	10	14	4	..	229	9
Lemons	13	61	56	13	6	9	6	8	33	16	11	..	232	8
Apple flavoring and molasses.....	12	63	62	16	14	11	11	6	16	17	5	..	233	7
Apple flavoring	12	70	65	18	13	3	3	42	7	6	8	..	247	6
Total number feeding during each hour.....	118	546	732	190	126	155	147	211	168	174	107			
Rank of each hour in relation to number feeding.....	10	2	1	4	9	7	8	3	6	5	11			
Hourly mean temperature	70	71	72	72	73	72	72	73	72	72	70			71.7
Hourly mean relative humidity.....	54	53	53	51	51	53	53	52	53	49	50			52
Sky (C = Clear; D = Overcast).....	C	C	C	C	C	C	D	C	C	C	C			

TABLE III

GRASSHOPPER BAIT EXPERIMENTS—HARNEY, MINN., JULY 1, 1923

Bait ingredients other than bran, arsenic, and water		Number of grasshoppers feeding at baits during each hour														Total	Rank		
		7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7						
Amyl acetate and molasses.....	Formula 1	5	19	14	15	22	37	0	0	0	0	0	0	112	1				
Amyl acetate	Formula 2	5	8	8	15	49	12	0	0	0	0	0	0	97	2				
Butyl acetate and molasses.....	Formula 3	3	11	6	9	41	13	0	0	0	0	0	0	83	4				
Butyl acetate	Formula 4	2	9	13	8	12	29	0	0	0	0	0	0	73	5				
Propyl acetate and molasses	Formula 5	1	13	3	25	8	14	0	0	0	0	0	0	64	6				
Propyl acetate	Formula 6	3	21	9	13	17	33	0	0	0	0	0	0	96	3				
Lemons and molasses	Formula 7	1	6	11	12	16	12	0	0	0	0	0	0	58	7				
Lenous	Formula 8	1	10	6	6	13	9	0	0	0	0	0	0	45	10				
Apple flavoring and molasses.....	Formula 9	0	6	5	8	7	22	0	0	0	0	0	0	48	9				
Apple flavoring	Formula 10	0	5	10	14	7	15	0	0	0	0	0	0	51	8				
Total number feeding during each hour.....		21	108	85	125	192	196									Mean for day			
Rank of each hour in relation to number feeding.....		6	3	5	4	2	1												
Hourly mean temperature		62	64	66	70	72	70	60	58										
Hourly mean relative humidity, per cent.....		86	84	83	69	65	72	90	93										
Sky (C = Clear; D = Overcast).....		D	D	D	C	C	C	D	D	D									

TABLE IV
GRASSHOPPER BAIT EXPERIMENTS—HARNEY, MINN., JULY 2, 1923

Bait ingredients other than bran, arsenic, and water		Number of grasshoppers feeding at baits during each hour														Total	Rank
		7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7				
Amyl acetate and molasses.....	Formula 1	4	52	79	23	56	70	39	46	102	127	35	..	633	1		
Amyl acetate	Formula 2	0	34	63	25	44	42	20	40	106	84	44	..	502	2		
Butyl acetate and molasses.....	Formula 3	0	31	50	19	55	70	45	35	106	66	24	..	501	3		
Butyl acetate	Formula 4	0	8	32	15	45	48	26	66	66	112	52	..	470	5		
Propyl acetate and molasses.....	Formula 5	1	13	50	20	40	64	23	46	72	149	22	..	500	4		
Propyl acetate	Formula 6	0	17	40	17	32	41	36	31	58	87	7	..	366	10		
Lemons and molasses	Formula 7	0	4	41	12	40	39	28	46	100	77	35	..	422	7		
Lemons	Formula 8	0	12	41	13	32	69	16	85	57	90	26	..	441	6		
Apple flavoring and molasses.....	Formula 9	0	9	47	12	38	42	22	80	67	82	15	..	414	8		
Apple flavoring	Formula 10	0	15	23	15	41	46	21	50	61	87	10	..	369	9		
Total number feeding during each hour.....																270	
Rank of each hour in relation to number feeding.....																Mean for day	
Hourly mean temperature, degrees F.....																70.1	
Hourly mean relative humidity, per cent.....																62.8	
Sky (C = Clear; D = Overcast).....																	

CRASSHOPPER BAIT EXPERIMENTS--HARNEY, MINN., JULY 8, 1923

Bait ingredients other than bran, arsenic, and water	Number of grasshoppers feeding at baits during each hour											Total	Rank		
	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6			6-7	
Amyl acetate and molasses.....	Formula 1	0	0	5	25	8	11	8	5	8	3	9	13	95	3
Amyl acetate	Formula 2	0	0	4	14	4	5	8	7	8	13	17	4	84	4
Butyl acetate and molasses.....	Formula 3	0	0	2	25	16	1	9	10	10	13	30	32	148	1
Butyl acetate	Formula 4	0	0	1	23	6	6	2	1	18	9	10	24	99	2
Propyl acetate and molasses	Formula 5	0	0	2	26	9	6	13	3	12	5	7	16	99	2
Propyl acetate	Formula 6	0	0	2	19	4	4	2	3	0	1	2	12	49	9
Lemons and molasses	Formula 7	0	0	0	14	7	2	5	5	5	2	6	13	59	7
Lemons	Formula 8	0	0	0	24	9	6	6	7	6	3	7	4	72	6
Apple flavoring and molasses.....	Formula 9	0	0	0	18	6	4	3	1	8	8	6	27	81	5
Apple flavoring	Formula 10	0	0	1	20	13	7	1	2	1	3	2	7	57	9
Molasses	Formula 11	0	0	2	22	8	5	2	2	3	7	4	26	81	5
Total number feeding during each hour.....															
Rank of each hour in relation to number feeding.....															
Hourly mean temperature															
Hourly mean relative humidity.....															
Hourly mean relative humidity.....															
Wind velocity															
Sky (C = Clear; D = Overcast).....															
														Mean for day	
														924	
														80	
														77.5	
														2.8	
														C	
														C	
														C	
														C	

TABLE VI
GRASSHOPPER BAIT EXPERIMENTS—HARNEY, MINN., JULY 9, 1923

Bait ingredients other than bran, arsenic, and water	Number of grasshoppers feeding at baits during each hour												Total	Rank	
	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7			
Amyl acetate and molasses.....	Formula 1	28	10	15	2	1	4	4	9	9	11	0	..	89	3
Amyl acetate	Formula 2	25	8	12	5	4	6	5	9	12	6	0	..	92	2
Butyl acetate and molasses.....	Formula 3	20	20	8	10	2	5	8	3	11	16	0	..	85	4
Butyl acetate	Formula 4	8	9	3	11	4	2	3	8	9	3	0	..	60	7
Propyl acetate and molasses	Formula 5	24	26	15	6	3	2	4	5	5	5	0	..	95	1
Propyl acetate	Formula 6	9	4	3	4	3	2	6	2	8	3	0	..	44	9
Lemons and molasses	Formula 7	7	4	7	4	1	2	0	4	8	1	0	..	38	10
Lemons	Formula 8	7	5	8	3	5	1	3	1	5	12	0	..	50	8
Apple flavoring and molasses.....	Formula 9	14	8	12	7	3	1	1	3	10	20	0	..	61	6
Apple flavoring	Formula 10	10	9	1	1	1	0	1	3	5	5	0	..	36	11
Molasses	Formula 11	22	10	6	5	2	1	8	3	6	3	0	..	66	5
Total number feeding during each hour.....															
Rank of each hour in relation to number feeding.....															
Hourly mean temperature															
Hourly mean relative humidity.....															
Wind velocity, miles per hour															
Sky (C = Clear; D = Overcast).....															
														717	Mean for day
														82.1	
														77	
														100	
														2.6	
														C	
														C	
														C	
														C	
														D	
														C	
														C	
														C	

TABLE VII

RATING OF BAITS ACCORDING TO TOTAL NUMBER OF GRASSHOPPERS FEEDING. FIRST SERIES OF EXPERIMENTS AT HARNEY, MINN., JUNE 29-JULY 9, 1923

Bait ingredients other than bran, arsenic, and water	Number of grasshoppers feeding at baits							Total	Rank
	June 29	June 30	July 1	July 2	July 8	July 9			
Amyl acetate and molasses.....	364	420	112	633	95	89	1713	1	
Amyl acetate	327	287	97	502	84	92	1389	2	
Butyl acetate and molasses.....	257	266	83	501	148	85	1340	4	
Butl acetate	265	200	73	470	99	60	1167	6	
Propyl acetate and molasses.....	324	267	64	500	99	95	1349	3	
Propyl acetate	261	293	96	366	49	44	1109	8	
Lemons and molasses.....	335	229	58	422	59	38	1141	7	
Lemons	342	232	45	441	72	50	1182	5	
Apple flavoring and molasses.....	236	233	48	414	81	61	1073	9	
Apple flavoring	246	247	51	364	57	36	1001	10	

If the total number of grasshoppers feeding at both molasses and non-molasses baits of each attractant is expressed in one set of figures, the following is the rating of the attractants used:

Amyl acetate baits attracted 3102 grasshoppers.
 Butyl acetate baits attracted 2507 grasshoppers.
 Propyl acetate baits attracted 2458 grasshoppers.
 Lemon baits attracted 2323 grasshoppers.
 Apple flavoring baits attracted 2074 grasshoppers.

Classifying the different attractants according to the number of times each ranked first during the 59 hourly periods of the experiment (See Table VIII), the following results are obtained:

Amyl acetate baits ranked first during 28 hours.
 Butyl acetate baits ranked first during 16 hours.
 Propyl acetate baits ranked first during 10 hours.
 Lemon baits ranked first during 5 hours.
 Apple flavoring baits ranked first during 0 hours.

A comparison of the ten different baits based on their rank during each hourly period was made as follows: A bait ranking first during one hour was credited with a weight of 10, second place with 9, third with 8, and so on down, tenth place receiving a weight of 1. Weights were distributed in this way for every hour of the experiment. The result of adding the weights credited to each bait is shown in Table VIII. Comparing these results with the ranking based on the total number of grasshoppers feeding for the entire period, as shown in Table VII, several changes will be noted. Butyl acetate and molasses (formula 3) is third instead of fourth; butyl acetate (formula 4) is fifth instead of sixth; propyl acetate and molasses (formula 5) is fourth instead of third; propyl acetate (formula 6) is sixth instead of eighth; lemons and molasses (formula 7) is ninth instead of seventh; lemons (formula 8) is seventh instead of fifth; apple flavoring and molasses (formula 9) is eighth instead of ninth.

If the weights of both molasses and non-molasses baits of each attractant are combined the following rating is obtained:

Amyl acetate baits.....	853 weights
Butyl acetate baits.....	680 weights
Propyl acetate baits	636 weights
Lemon baits	547 weights
Apple flavoring baits	526 weights

This is in exactly the same order as was found by the first two methods of comparison and it may therefore be said that amyl acetate, butyl acetate, propyl acetate, lemons, and synthetic apple flavoring rank in the order named in their effectiveness as attractants in grasshopper baits in this experiment.

TABLE VIII
 RATING OF GRASSHOPPER BAITS ACCORDING TO HOURLY RANK
 FIRST SERIES OF EXPERIMENTS, JUNE 27-JULY 19, 1923

Bait ingredients other than bran, arsenic, and water		Number of hours rank- ing first	Total weights based on all hourly rankings*
Amyl acetate and molasses.....	Formula 1	20	485 (1)
Amyl acetate	Formula 2	8	368 (2)
Butyl acetate and molasses.....	Formula 3	12	365 (3)
Butyl acetate	Formula 4	4	315 (5)
Propyl acetate and molasses.....	Formula 5	7	356 (4)
Propyl acetate	Formula 6	3	280 (6)
Lemons and molasses.....	Formula 7	2	269 (9)
Lemons	Formula 8	3	278 (7)
Apple flavoring and molasses.....	Formula 9	0	272 (8)
Apple flavoring	Formula 10	0	254 (10)

* Weights of 10, 9, 8, 7, 6, 5, 4, 3, 2, and 1 were credited for each hour that a bait ranked first, second, third, etc.

DOES MOLASSES INCREASE EFFECTIVENESS OF GRASSHOPPER BAITS?

A study of the summary of results given in Table VII shows that the baits most heavily fed upon were those containing molasses in addition to some other attractant. An exception is to be noted in the case of the bait containing lemons, which in five out of six days gave better results when molasses was not used. Adding the six day totals it is found that 6616 grasshoppers fed upon molasses baits as against 5848 on baits not containing molasses.

The increased effectiveness of baits containing molasses is more strikingly brought out by referring to the hourly ranking, baits containing molasses ranking first during 41 hours of the experiment while those without molasses ranked first during only 18 hours. Molasses seemed particularly to increase the effectiveness of baits having amyl acetate as an attractant.

SECOND SERIES OF GRASSHOPPER BAIT EXPERIMENTS

VARIOUS ATTRACTANTS USED WITH AND WITHOUT SALT

In the second series of experiments it was desired to test again the relative value of the attractants used in the first series and to determine whether the addition of salt made the baits more effective. The following combinations were used:

Formula 12—Bran arsenic mash plus amyl acetate, molasses, and salt

"	13	"	"	"	"	amyl acetate and molasses
"	14	"	"	"	"	butyl acetate, molasses, and salt
"	15	"	"	"	"	butyl acetate and molasses
"	16	"	"	"	"	lemons, molasses, and salt
"	17	"	"	"	"	lemons and molasses
"	18	"	"	"	"	apple flavoring, molasses, and salt
"	19	"	"	"	"	apple flavoring and molasses
"	20	"	"	"	"	molasses and salt
"	21	"	"	"	"	molasses alone
"	22	"	"	"	"	salt alone.

This series was tried out at Harney for 5 days—July 10 to 14. The grasshoppers at this time were all adult and were more widely scattered than during the first series and as a result the numbers reported feeding are not so large. The detailed results for the five days are given in Tables IX to XIII.

RELATIVE VALUE OF ATTRACTANTS USED

Judging the second series of bait tests on the basis of the total number of grasshoppers attracted, no particular bait stands out as distinctly better than all the others as did amyl acetate and molasses (formula 1) in the first series. Turning to the summary of results in Table XIV it will be noted that a combination of amyl acetate, molasses, and salt (formula 12) heads the list in number of grasshoppers feeding but it is so closely approached by salt alone (formula 22), amyl acetate and molasses (formula 13), and molasses and salt (formula 20) that the differences between them are undoubtedly less than the experimental error.

If the totals for salt and non-salt baits are added and the number of grasshoppers feeding at baits containing the same attractants is expressed in one set of figures, the various materials will be found to have attracted grasshoppers in the following order:

Amyl acetate baits attracted 676 grasshoppers.
 Apple flavoring baits attracted 523 grasshoppers.
 Butyl acetate baits attracted 471 grasshoppers.
 Lemon baits attracted 459 grasshoppers.

This corresponds to the ranking of the same materials in the first series of experiments except that apple flavoring jumped from last to second place.

This change may possibly be due to the presence of salt in formula 18. It is significant that formulas 9 and 19, each consisting of apple flavoring and molasses, rank ninth in both the first and the second series of experiments and that formula 18, which differs only in having salt added, ranks fifth.

TABLE IX
GRASSHOPPER BAIT EXPERIMENTS—HARNEY, MINN., JULY 10, 1923

Bait ingredients other than bran, arsenic, and water	Number of grasshoppers feeding at baits during day													Total	Rank
	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7			
Formula 12	0	0	0	0	0	0	0	12	7	7	4	..	30	7	
Formula 13	0	0	0	0	0	0	0	3	2	19	12	..	36	4	
Formula 14	0	0	0	0	0	0	0	13	3	13	3	..	32	6	
Formula 15	0	0	0	0	0	0	0	2	4	7	11	..	24	9	
Formula 16	0	0	0	0	0	0	0	13	4	4	2	..	23	10	
Formula 17	0	0	0	0	0	0	0	5	3	15	4	..	27	8	
Formula 18	0	0	0	0	0	0	0	5	3	17	5	..	30	7	
Formula 19	0	0	0	0	0	0	0	14	2	17	13	..	46	1	
Formula 20								5	3	10	16	..	34	5	
Formula 21								3	2	22	15	..	42	3	
Formula 22								6	2	21	14	..	43	2	
Total number feeding during each hour.....															
Rank of each hour in relation to number feeding.....															
Hourly mean temperature.....															
Hourly mean relative humidity.....															
Wind velocity.....															
Sky (C = Clear; D = Overcast).....															
													Mean for day		

Mean for day

TABLE X
GRASSHOPPER BAIT EXPERIMENTS—HARNEY, MINN., JULY 11, 1923

[illegible]

TABLE XII
GRASSHOPPER BAIT EXPERIMENTS—HARNEY, MINN., JULY 13, 1923

Bait ingredients other than bran, arsenic, and water	Number of grasshoppers feeding at baits during each hour												Total	Rank
	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7		
Amyl acetate, molasses, and salt.....	10	10	18	13	12	8	3	5	5	2	3	1	90	1
Amyl acetate and molasses.....	2	21	20	11	5	6	6	1	4	8	2	3	89	2
Butyl acetate, molasses, and salt.....	5	15	17	8	6	2	4	3	1	1	4	1	67	6
Butyl acetate and molasses.....	2	2	10	2	4	2	4	2	1	3	0	0	32	9
Lemons, molasses, and salt.....	3	9	10	6	6	7	8	7	4	1	4	0	65	7
Lemons and molasses.....	1	4	8	4	5	2	4	0	2	1	0	0	31	10
Apple flavoring, molasses, and salt.....	2	28	13	5	4	4	7	3	1	2	5	5	79	3
Apple flavoring and molasses.....	4	9	13	4	3	3	0	3	0	4	3	0	46	8
Molasses and salt.....	2	9	17	12	6	17	5	4	1	1	0	0	74	4
Molasses	0	6	11	5	8	5	9	11	8	6	2	2	73	5
Salt	1	21	23	9	4	13	8	2	1	0	5	2	89	2
Total number feeding during each hour.....	32	134	160	79	63	69	58	41	28	29	28	14	Mean for day 78.9 59.0	
Rank of each hour in relation to number feeding.....	8	2	1	3	5	4	6	7	10	9	10	11		
Hourly mean temperature	70	75	77	79	80	81	82	82	82	82	78	75		
Hourly mean relative humidity	59	57	56	50	47	49	50	49	54	52	57	70		
Wind velocity	2.0	1.6	1.5	1.6	1.6	1.7	1.9	2.9	3.4	2.4	2.4	2.6		
Sky (C = Clear; D = Overcast).....	C	C	C	C	C	C	C	C	C	C	C	C		

TABLE XIII
GRASSHOPPER BAIT EXPERIMENTS—HARNEY, MINN., JULY 14, 1923

[illegible]

Judging the attractants on the basis of the number of hourly periods that each ranked first, it is found that the order is the same as on the basis of total number of grasshoppers feeding.

Amyl acetate baits ranked first during 17 hours.

Apple flavoring baits ranked first during 8 hours.

Butyl acetate baits ranked first during 4 hours.

Lemon baits ranked first during 2 hours.

Comparing the various baits by the system of weighting that was used in the first series, amyl acetate, molasses, and salt (formula 12) has a more decided advantage than was shown by judging the baits by the total number of grasshoppers attracted. See Tables XIV and XV. Several other slight changes also occur: butyl acetate, molasses, and salt (formula 14) is eighth instead of seventh; butyl acetate and molasses (formula 15) is ninth instead of tenth; lemons, molasses, and salt is seventh instead of eighth; apple flavoring and molasses is tenth instead of ninth.

If the weights of salt and non-salt baits of each attractant are combined, the following rating is obtained:

Amyl acetate baits	608 weights
Apple flavoring baits	459 weights
Lemon baits	412 weights
Butyl acetate baits.....	411 weights

This is in the same ranking as obtained by the first two methods with the exception that in the last method lemon and butyl acetate baits are practically equal.

Molasses is not listed among the attractants, but it should be noted that bait No. 21, containing only molasses, was fed upon by a greater number of grasshoppers than Nos. 14, 15, 16, 17, and 19, all of which contained an attractant plus molasses. This fact, together with the greater effectiveness of the molasses baits in the first series of experiments, would seem to indicate that molasses should be retained as one of the essential ingredients of grasshopper baits. Whether grasshoppers are attracted by the odor of molasses or feed in greater numbers because baits containing it remain moist longer, has not been determined.

TABLE XIV
RATING OF BAITS ACCORDING TO TOTAL NUMBER OF GRASSHOPPERS FEEDING. SECOND SERIES OF EXPERIMENTS, JULY 10-14, 1923

Bait ingredients other than bran, arsenic, and water	Number of grasshoppers at baits							Total	Rank
	July 10	July 11	July 12	July 13	July 14				
Amyl acetate, molasses, and salt.....	30	114	91	90	24			349	1
Amyl acetate and molasses.....	36	90	94	89	18			327	3
Butyl acetate, molasses, and salt.....	32	77	75	67	5			256	7
Butyl acetate and molasses.....	24	85	60	32	14			215	10
Lemons, molasses, and salt.....	23	87	63	65	7			245	8
Lemons and molasses.....	27	76	70	31	10			214	11
Apple flavoring, molasses, and salt.....	30	95	85	79	10			209	5
Apple flavoring and molasses.....	46	76	52	46	4			224	9
Molasses and salt.....	34	116	81	74	16			321	4
Molasses	42	57	71	73	17			260	6
Salt	43	68	113	89	19			332	2

TABLE XV
RATING OF GRASSHOPPER BAITS ACCORDING TO HOURLY RANK
SECOND SERIES OF EXPERIMENTS, JULY 10-14, 1923

Bait ingredients other than bran, arsenic, and water		Number of hours rank- ing first	Total weights based on all hourly rankings*
Amyl acetate, molasses, and salt.....	Formula 12	10	323.0 (1)
Amyl acetate and molasses.....	Formula 13	7	285.5 (3)
Butyl acetate, molasses, and salt.....	Formula 14	3	216.0 (8)
Butyl acetate and molasses.....	Formula 15	1	195.0 (9)
Lemons, molasses, and salt.....	Formula 16	2	230.0 (7)
Lemons and molasses.....	Formula 17	0	182.0 (11)
Apple flavoring, molasses, and salt.....	Formula 18	7	269.0 (5)
Apple flavoring and molasses	Formula 19	1	190.0 (10)
Molasses and salt	Formula 20	4	280.5 (4)
Molasses	Formula 21	5	235.5 (6)
Salt	Formula 22	6	286.0 (2)

* Weights of 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, or 1, were credited for each hour that a bait ranked first, second, third, etc.

DOES SALT INCREASE THE EFFECTIVENESS OF GRASSHOPPER BAITS?

A study of the summary of results shown in Table XIV shows that in every case the attractant and molasses plus salt gave better results than the attractant and molasses used alone. Baits containing salt attracted 1470 grasshoppers while baits similar except for the salt attracted 1240, a decrease of 18 per cent. Baits containing salt ranked first during 26 hourly periods while similar baits without salt ranked first during only 14 hourly periods.

Salt used alone (formula 22) ranked remarkably high, being fed upon by more grasshoppers than molasses and salt combined (formula 20) and by almost as many as fed upon amyl acetate, molasses, and salt (formula 12). On the basis of the figures presented it might be inferred that salt could be used to replace both attractants and molasses in grasshopper baits, but the length of the experiment was too short and the number of grasshoppers feeding too small to warrant making such a statement. Moreover, salt baits were not tried against immature grasshoppers which, according to Swenk (1923), are less fond of salt than are the adults. It seems plain, however, that salt is fully as important in grasshopper bait as either molasses or attractants, and that under some conditions a bait made from bran, arsenic, salt, and water might give very satisfactory results.

WHAT IS THE BEST GRASSHOPPER BAIT FOR MINNESOTA?

The main purpose of the experimental work with grasshopper baits was to work out a combination of materials that could be used economically and effectively in killing grasshoppers under Minnesota conditions. It may therefore be well briefly to review the facts learned in regard to the various materials that were used in the experiments.

Amyl acetate was consistently the most effective of the various attractants used. Butyl and propyl acetate gave good results but were not so effective as amyl acetate and are more expensive and difficult to obtain. Lemons were less effective in attracting grasshoppers than any of the acetates and are much more expensive than amyl acetate. Synthetic apple flavoring gave very poor results when used alone or with molasses but gave fairly good results when combined with salt. Its cost is prohibitive, however, and there is no reason for using this material in place of the cheaper and better known attractants.

Salt and molasses increased the effectiveness of any bait to which either was added except lemon baits, which were not improved by adding molasses.

It may therefore be concluded from the present experiments that aside from the basic ingredients of bran, arsenic, and water, the most important materials to be included in grasshopper baits are amyl acetate, molasses, and salt. The relative importance of these three materials seems to vary according to conditions, each material outranking the others at various times.

Amyl acetate with its penetrating fruity odor will attract grasshoppers over distances of several feet and tends to bring them immediately in contact with the poisoned bait. Molasses delays the drying out of the bran and may possibly attract grasshoppers by its odor and prolong their feeding because of the sweetness which it adds to the bran. Salt is so well liked by grasshoppers that they will even eat rake handles that have become salty from perspiration and it would therefore be expected that the addition of salt would make poisoned bran mash more attractive to them. It seems logical to believe that the best bait should include all three of these materials, thus combining all their advantages and extending the usefulness of the bait over a wider range of conditions. The formula for such a bait would be as follows:

Coarse bran	100 pounds
Arsenic	5 pounds
Salt	5 pounds
Molasses	2 gallons
Amyl acetate	3 ounces
Water	10-12 gallons

This is not a new formula but is one that has been extensively and successfully used in Montana and other western states. It contains the materials found most effective in the experiments reported on in this paper and is therefore recommended for use in Minnesota.

II. RESPONSE TO METEOROLOGICAL FACTORS EFFECTS OF TEMPERATURE

The trained observer who studies the clear-winged grasshopper (*Camnula pellucida* Scudder) can not fail to be impressed with the fact that it is a great lover of warmth and sunshine and that its daily range of activities is very largely controlled by temperature. During cold weather it seeks any shelter that offers a few degrees more of warmth than the open air, and so universal is this habit that a field that is literally swarming with grasshoppers at mid-day may not appear to contain a single grasshopper an hour after sundown. As the morning sun warms the air, the grasshoppers slowly crawl from their hiding places, seek a position in the sun, and seem to fairly revel in the warmth of its rays. At such times they cluster thickly on stumps, boards, dry sod, etc., taking advantage of the fact that such materials are already several degrees above air temperature. As the temperature rises further the grasshoppers start moving about and are active during the greater part of the day in ordinary summer weather. If it is extremely warm and the ground gets too hot for comfort, the grasshoppers choose their own temperature by crawling up on weeds or blades of grass, a distance of two inches just above the earth offering a surprisingly wide range of temperature. Just before sundown they again seek stumps, stones, and other objects which have retained considerable heat after the air has begun to cool, and here arrange themselves to get the fullest effect of the slanting rays of the setting sun. As the air continues to cool and the objects on which the grasshoppers are roosting give up their heat, they gradually crawl to more protected situations and finally disappear from sight.

These general facts are known to all students of Orthoptera, but very few records can be found in the literature which state definitely the exact temperatures at which the various activities take place. During the field work with grasshopper baits at Harney and later with artificially controlled temperature in the laboratory, definite data covering these points were obtained and are here presented.

LOWER TEMPERATURE LIMITS OF ACTIVITY

In the field *Camnula pellucida* is rarely seen moving about at temperatures below 60° F. (15.5° C.) After a night when the temperature has ranged from 50 to 60° F., they are very sluggish and will not move unless disturbed. Exposure to a temperature of 40° F. (5° C.) for several hours renders them completely dormant, altho it is by no means fatal. Fatal temperatures were determined by placing first and second instar nymphs in an air conditioning cabinet and holding them for 12-hour periods at constant temperatures. This would roughly correspond to submitting them to a single night of low temperature. Lots of twenty grasshoppers were submitted to the following temperatures: 32° F. (0° C.), 30.2° F. (-1° C.), 28.4° F. (-2° C.), 26.6° F. (-3° C.), 24.8° F. (-4° C.), 23° F. (-5° C.), 21° F. (-6° C.), 19.4° F. (-7° C.), and 17.6° F. (-8° C.). None was killed until a temperature of 19.4° F. (-7° C.) was reached, and 12 out of the 20 specimens survived that temperature for the 12-hour period. At 17.6° F. (-8° C.) none survived the 12-hour exposure. It may therefore be assumed that the lowest temperatures at which *Camnula pellucida* could survive for several hours would be between 19 and 17° F., or -7 and -8° C.

When the air temperature goes above 60° F. (15.5° C.) the more venturesome grasshoppers crawl from their hiding places and at 65° F. (18.3° C.) nearly all will be in the open, but moving only enough to find favorable spots where they may bask in the sunshine. From 65 to 68° F. (20° C.) may be termed the "warming-up period," as the great majority of the grasshoppers seem content to remain motionless, their bodies always broadside to the sun and with legs and wings arranged so as to receive the maximum amount of solar heat. After the air temperature has gone above 68° F. they begin to move about and to enter upon the normal activities of the day.

Whenever the temperature again drops to 68° F. and below, a reversal of this procedure takes place. Field notes at Harney for July 10, 1923, illustrate this point. At 4:30 p.m. the temperature had dropped to 68° and the grasshoppers started crawling to the more sunny spots on stumps and stones, all feeding and other activities practically ceasing. At 5:30 the temperature was 65° and they were beginning to leave their roosting places. At 6:00 p.m. with the air temperature at 62° a few remained on stones and stumps, but nearly all had crawled into cracks in the stumps, clumps of grass, under stones, or other protection. When the temperature reached 60° at 7:30 p.m. not a grasshopper was in sight. That this was a temperature reaction rather than a light reaction is shown by the fact that two days

earlier when the temperature at 7:30 p.m. stood at 75°, all the grasshoppers remained in the open, many of them moving about and feeding.

UPPER TEMPERATURE LIMITS OF ACTIVITY

The point at which the normal activity of *C. pellucida* is brought to a close by high temperature is not as definitely known as are the lower limits. The writer has observed repeatedly, however, both in Montana and in Minnesota, that when the air temperature reaches approximately 85° F. (29.4° C.) the grasshoppers leave the ground and seek a more desirable temperature by climbing weeds and blades of grass. The temperature at the surface of the ground at such times is of course much higher than that of the air four feet above the ground. The difference as well as the wide range of temperature from which the grasshopper can choose by merely moving two inches up or down a grass blade, is well shown in comparative temperatures noted at Harney on July 9, 1923. The surface of the ground was covered with dry sod and its temperature was taken by allowing the bulb of a mercury thermometer suspended from a fence wire to rest lightly upon the sod. Another thermometer hanging from the wire with its bulb two inches above the sod recorded the temperature at that height. Air temperature was taken at a height of four feet.

Time	Temperature of sod	Temperature 2 inches above ground	Air temperature at 4 feet
11:30 a.m.	136.6° F. (57° C.)	96.8° F. (36° C.)	90° F. (32.2° C.)
12:30 p.m.	139° F. (59.5° C.)	100.4° F. (38° C.)	92° F. (33.3° C.)
1:30 p.m.	105.8° F. (41° C.)	89.6° F. (32° C.)	85° F. (29.4° C.)
2:30 p.m.	96.8° F. (36° C.)	86° F. (30° C.)	77° F. (25° C.)

From these data it is seen that when the air temperature is at 90° F. the surface of dry soddy ground may register a temperature of 136.6° F. and that a grasshopper may reach a position 39.8 degrees cooler than the surface of the ground by climbing two inches up a weed or blade of grass.

Several hundred adults of *C. pellucida* confined in a temperature cabinet where all the air was at a uniform temperature, acted quite normally up to approximately 110° F. (43.3° C.), but became very much excited if carried much beyond that point.

In order to find out what temperature would be chosen if a choice were given, the following experiment was carried out. A sheet of glass was covered with paper and heated from below by an electric lamp so that the area immediately above the lamp finally reached a constant temperature of approximately 140° F. (60° C.) with correspondingly lower temperatures as the distance from the lamp was in-

creased, the temperature at the edge of the glass being that of the room, which was 65° F. (18.3° C.). Fifty first and second instar nymphs of *C. pellucida* were released on the prepared surface of the glass and left undisturbed for several hours. After wandering aimlessly for some time they came to rest arranged in a very definite circle around the central area. Temperature readings made anywhere on this circle were always between 98 and 100° F. (36.6 and 37.7° C.). This experiment was repeated several times with similar results. The light intensity was somewhat greater in the center and the grasshoppers were undoubtedly attracted in that direction, but the fact that they never came to rest on areas warmer than 100° F. indicates that their aversion to higher temperature overcame their normally positive phototropism.

In the light of the field observations and laboratory experiments just discussed, it may be concluded that the normal activities of *C. pellucida* are disturbed whenever it finds itself on a surface or in air having temperatures higher than 100 to 110° F. (37.7 to 43.3° C.). Such temperature may be expected at the surface of the ground whenever the air temperature exceeds 85° F. (29.4° C.), but will vary considerably according to the nature of the ground covering.

Upper fatal temperatures were determined by the use of an air conditioning cabinet. An extended series of experiments with both nymphs and adults was carried out, the results of which will be only briefly outlined at this time. The grasshoppers were placed in the cabinet at a temperature of 65° F. (18.3° C.) and the temperature was then gradually raised at the rate of one degree Centigrade in from 5 to 10 minutes. Some interference with normal activity was generally noted at 104° F. (40° C.), and at 113° F. (45° C.) nearly all of the grasshoppers became very nervous and moved about excitedly. When the temperature reached 122° F. (50° C.) many grasshoppers suffered a partial paralysis of the hind legs and the weaker specimens went into heat rigor. The majority of specimens were not overcome until a temperature of 130° F. (54.5° C.) was reached and a few survived 5 to 10 minutes exposures at 136° F. (57.7° C.). Nikolsky (1918) states that nymphs of *Locusta migratoria* L. two days old were killed when exposed to a ground temperature of 127.4° F. (53° C.), but that when four and five days old they can stand temperatures up to 134.6 and 136.4° F. (57 and 58° C.).

TEMPERATURES AT WHICH VARIOUS ACTIVITIES TAKE PLACE

In preceding paragraphs it has been shown that the range of normal activity for *C. pellucida* extends from approximately 68° F. (20° C.) to about 104° F. (40° C.). There now remains a discussion of the temperatures at which such normal activities as feeding, molting, migrating, flying, mating, and egg laying take place.

Grasshoppers seldom feed on vegetation during the morning hours before the temperature reaches 68° F. (20° C.) and feeding is not at all general until it has reached 70° F. (21.1° C.) or above. Slight feeding has been noticed in the afternoon at 62° F. (16.6° C.), but as a rule all feeding stops at 68° F. (20° C.). In the field feeding was seldom witnessed at temperatures above 90° F. (32.2° C.), but in the temperature cabinet, feeding at grass and bran mash sometimes continued until a temperature of 113° F. (45° C.) was reached.

The temperatures at which maximum feeding at poisoned bran mash takes place will be more fully discussed under a separate heading.

Molting very seldom takes place at 68° F. (20° C.) or below. *C. pellucida* nymphs kept at a constant temperature of 68° F. accustomed themselves to feeding at this temperature and became quite plump but were apparently unable to molt. Nymphs fed at this temperature for several weeks will shed their skins in a few minutes when placed in a temperature of 72° F. (22.2° C.) or above. For a few days at Harney, when *C. pellucida* was transforming from the last nymphal instar to the adult stage, hundreds of grasshoppers were seen in the molting process. A few individuals in sunny locations would be seen shedding their skins as soon as the temperature reached 70° F. (21.2° C.), but the process was not general until the air was warmed to at least 72° F. (22.2° C.).

At Harney no migrations of *C. pellucida* were noticed. In Montana where the species is called "warrior grasshopper" because the young travel in armies, migrations are very common. In two instances when the temperature was noted they were found to cease traveling when the air temperature dropped below 70° F. (21.1° C.).

Uvarov (1923) states that the mean temperature arousing the first movements in the morning of nymphal bands of *L. migratoria* L. is in the neighborhood of 55.4 to 59° F. (13 to 15° C.) in the shade, but does not state the temperature at which the daily migrations actually start.

Adults of *C. pellucida* are strong flyers and when abundant sometimes take to the air in swarms. This has been observed many times in Montana and to a lesser extent at Harney. At the latter place considerable flying was noted on July 29, 1923. At 11:00 a.m. the air temperature was 77° F. (25° C.), and it was noticed that many grasshoppers were taking to the air. At 11:15 the sun went behind a slight cloud and the air temperature dropped to 72° F. (22.2° C.), all flying stopping immediately. In three minutes the sun was out again and in five minutes the air temperature had risen to 75° F. (23.8° C.) and flying began again and continued for several hours until the air tem-

perature fell below 72° F. (22.2° C.), after which no more flights were witnessed. In Montana, where extended flights were observed in one locality on six consecutive days, it was noted that flights did not begin until the air temperature had reached 74° F. (23.3° C.) and were at their maximum at from 75 to 78° F. (23.8 to 25.5° C.).

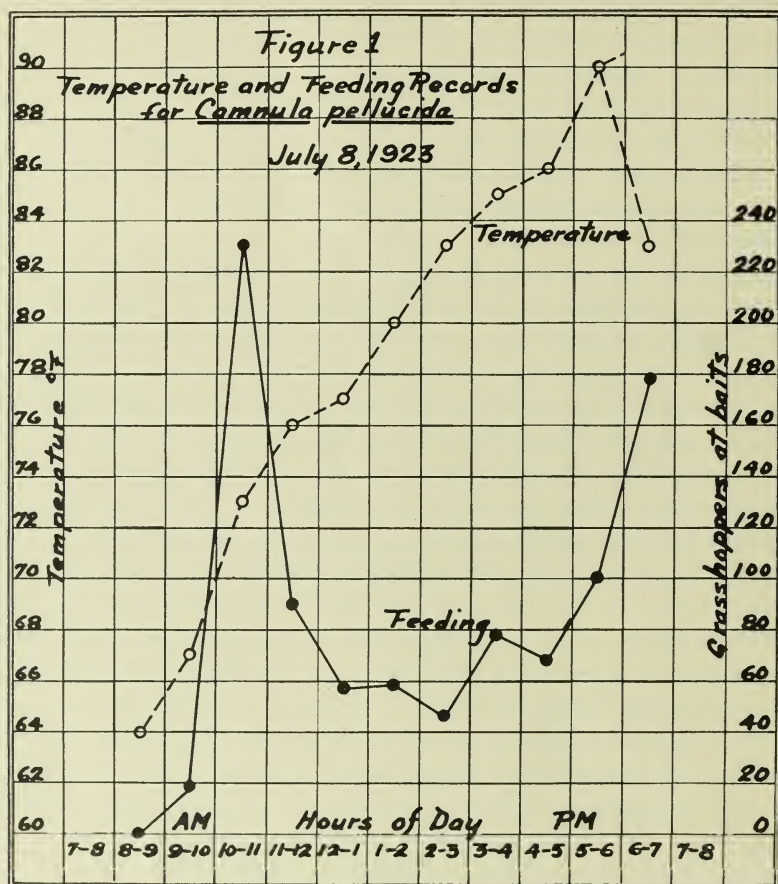
Mating is sometimes attempted by the males at temperatures as low as 65° F. (18.3° C.) but is uncommon below 68° F. (20° C.) and is at its height from 74 to 78° F. (23.3 to 25.5° C.). In the temperature cabinet mating continued up to 100° F. (37.7° C.), and several mating pairs did not separate until a temperature of 110° F. (43.3° C.) was reached.

Egg laying has not been witnessed at air temperatures below 72° F. (22.2° C.). On July 29, at Harney, the first egg laying of the day was carefully watched for. At 8:00 a.m. the air temperature was 70° F. (21.1° C.) and the females were actively moving about but two observers could not find any laying eggs. At 8:20 a female was found ovipositing, the air temperature then being 72° F. (22.2° C.). On the previous afternoon numerous females were depositing eggs when temperatures ranged from 74 to 77° F. (23.3 to 25° C.), but when the temperature fell to 73° F. (22.7° C.) egg laying decreased rapidly and at 72° F. (22.2° C.) only one ovipositing female was found in a ten-minute search. On the following day the air temperature in the morning did not reach 72° F. (22.2° C.) until 10:30, and not a female could be found laying eggs before that time. As the temperature rose above 72° F. egg laying began and at 78° F. (25.5° C.) was taking place very actively. Egg laden females placed in the temperature cabinet and subjected to high temperature are aroused to a perfect frenzy of oviposition and in several instances continued to lay eggs up to 130° F. (54.4° C.).

TEMPERATURE AT WHICH MAXIMUM FEEDING AT POISONED BRAN MASH OCCURS

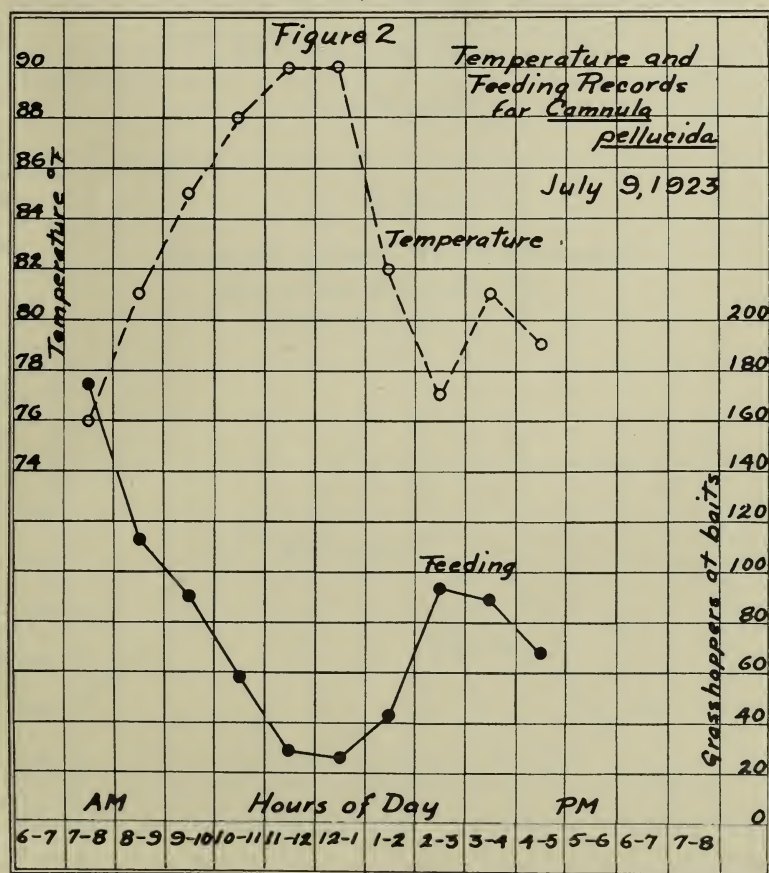
It is generally agreed that grasshoppers are most strongly attracted to poisoned bran mash when it is moist and giving off a distinct odor. It is also commonly recognized that at certain times grasshoppers will not feed at all no matter how attractive the bait and that at other times periods of maximum feeding occur during which every grasshopper seems to be looking for food. Keeping in mind these two facts it may be definitely stated that poisoned bran mash will give best results if it is scattered so that its period of greatest attractiveness coincides with the period of maximum feeding of the grasshoppers it is supposed to kill. As all the activities of *C. pellucida* have been shown to be greatly influenced by temperature, it is important to know how it affects feed-

ing at poisoned bran mash, for such knowledge would be of great value in making recommendations as to the correct time for scattering grasshopper bait in order to control this species.



Data on this point are available by referring to the experiments with poisoned bran mash reported earlier in this paper, the mean temperature for each hour of the day and the total number of grasshoppers feeding at all baits during that hour being given in the lower part of each of the tables containing data for single days. Graphs showing the daily relation between temperature and feeding from July 8 to 13, 1923, are shown in Figures 1 to 5. No graph is given for July 10, storms on that date preventing a full day's record. The particular period from July 8 to 13 was chosen because during that time conditions other than temperature were quite uniform. The grasshoppers were all adult, the infestation remained almost constant, and the methods of conducting the experiment were the same throughout the period.

On July 8 the temperature was low during the early morning hours but rose throughout the day and was abnormally high in the afternoon. Practically no feeding took place from 7 to 10 a.m., the temperature during that time not reaching above 67°F. (19.4°C.). From 10 to 11 a.m. a sudden jump in feeding took place, the maximum for the day occurring during this hour, the mean temperature being 73°F. (22.7°C.). As the temperature continued to rise the feeding slowed down and was slight throughout the day but reached a second high point between 6 and 7 p.m. after the temperature had begun to fall.

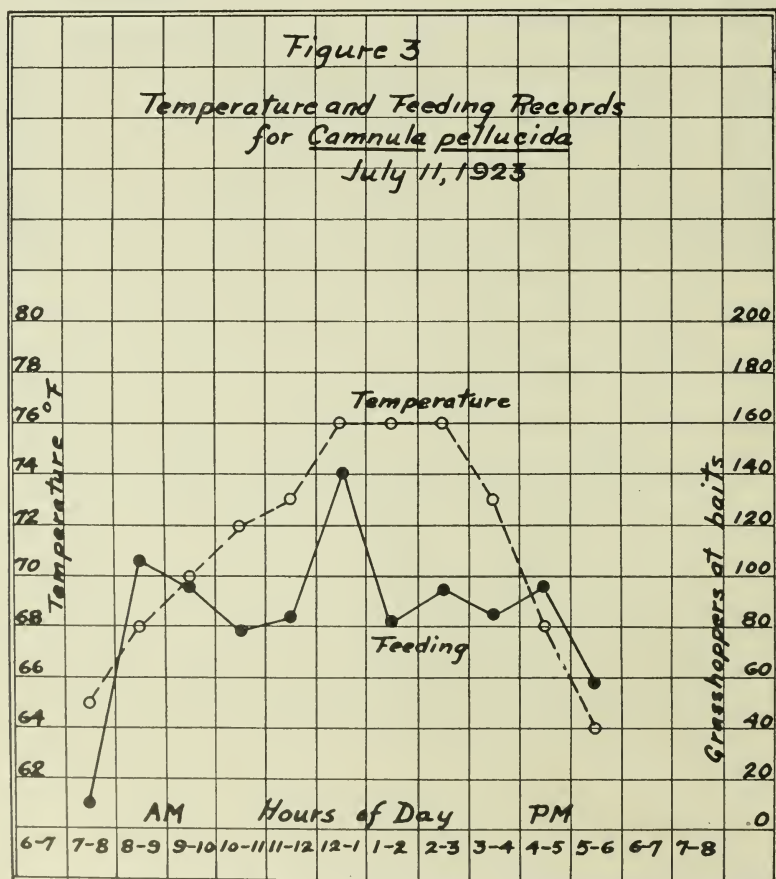


It should also be noted that feeding continued later in the afternoon than on any other day, owing undoubtedly to the sustained high temperature.

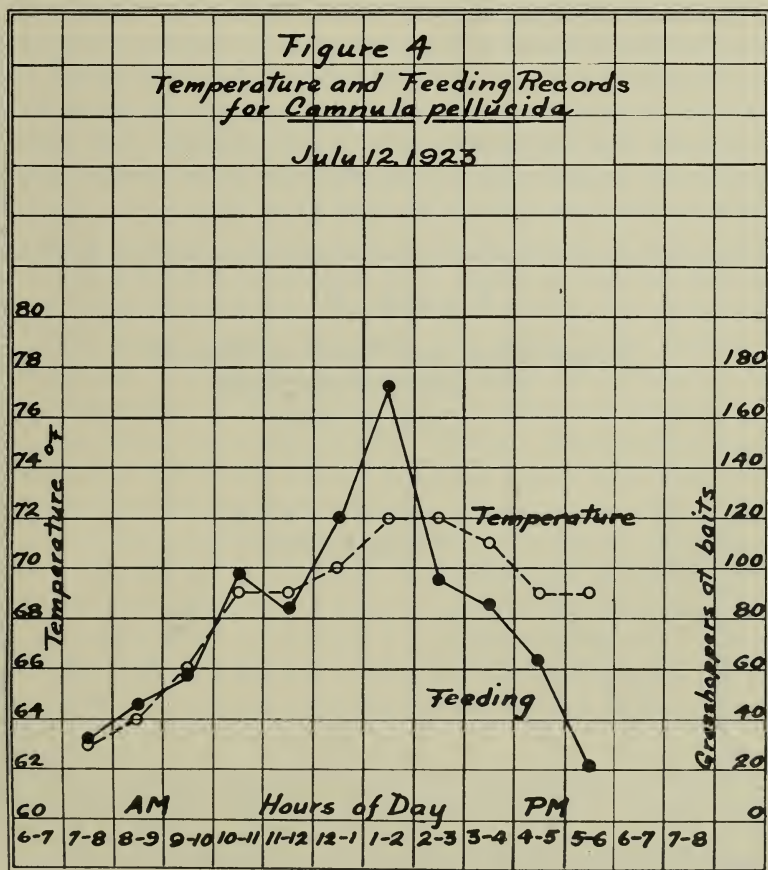
The morning of July 9 was abnormally warm and the hour of maximum feeding was much earlier in the day—between 7 and 8 a.m.

at a mean temperature of 76°F. (24.4°C.). As the temperature rose beyond 76°F. feeding declined and was at its lowest from 11 a.m. to 1 p.m., during which time the temperature stood at 90°F. (32.2°C.). With a sudden dropping of the temperature to 77°F. (25°C.) between 2 and 3 p.m., feeding took an upward turn but did not go as high as in the morning. The graph for July 11 shows a day of much more uniform temperature than the two preceding, and also shows that feeding was general over a longer period. Considerable feeding took place between 8 and 9 a.m. at a mean temperature of 68°F. (20.0°C.), but the maximum was not reached until between 12 m. and 1 p.m. at a mean temperature of 76°F. (24.4°C.).

July 12 was cool and the period of maximum feeding came rather late in the day—between 1 and 2 p.m.—at a mean temperature of 72°F. (22.2°C.) the highest hourly mean for the day.



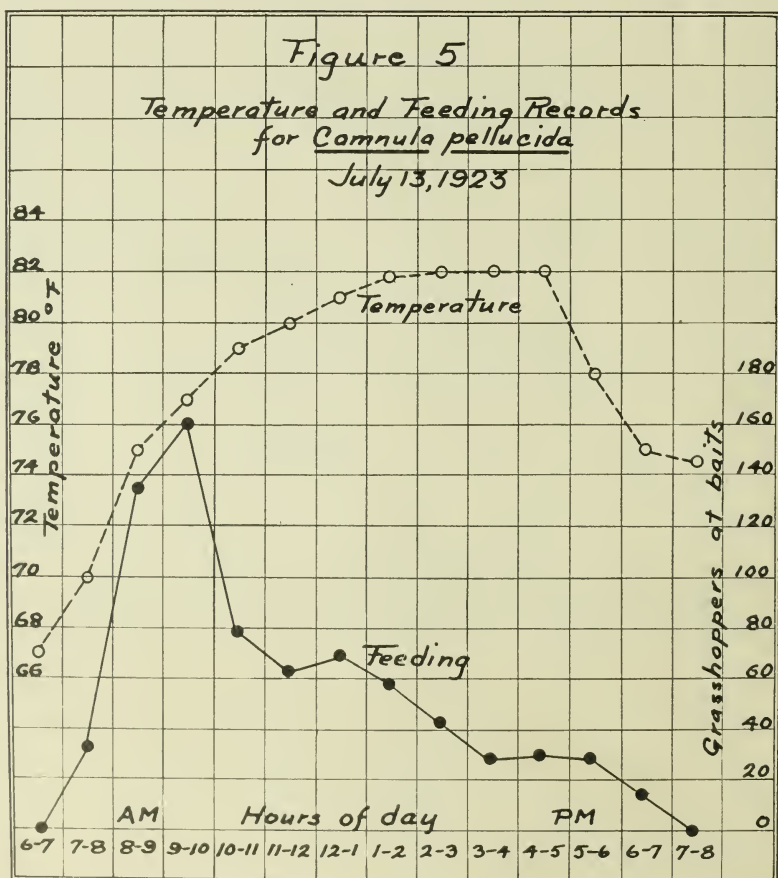
On July 13 the temperature rose quite rapidly during the early morning hours and the hour of greatest feeding was between 9 and 10 a.m. at a mean temperature of 77°F. (25°C.), altho feeding had been almost as heavy between 8 and 9 a.m. at a mean temperature of 75°F. (23.8°C.). As the temperature rose above 77°F. feeding fell off rapidly and no upward turn was noted in the late afternoon as was noticed on the warm days of July 8 and 9.



Summarizing the data used in the graphs, it may be said that *C. pellucida* feeds sparingly at poisoned bran mash at temperatures from 65 to 68°F. (18.3 to 20°C.), more actively at temperatures from 69 to 70°F. (20.5 to 21°C.), and most actively at temperatures from 71 to 77°F. (21.6 to 25°C.), feeding declining rapidly at higher temperatures than 77°F.

The hour of maximum feeding will generally occur during that hour of the day which first has a mean temperature of 73 to 77° F. (22.7 to 24° C.). On days when the maximum hourly mean is below these figures, the hour of heaviest feeding will generally occur during the hour when the highest temperature for the day is first reached.

Most recommendations as to when poisoned bran mash should be scattered are based on time rather than temperature. The data just presented show quite clearly, however, that the period of maximum feeding of *C. pellucida* by no means always occurs at the same hour of the day and that temperature is a better basis for making recommendations. In general it may be said that poisoned bran mash should never be put out at temperatures below 68° F. (20° C.) or above 80° F. (26.6° C.) and that best results are to be expected when it is scattered so that it will be moist and odorous when the air temperature for the day first reaches from 73 to 77° F. (22.7 to 25° C.).



IMPORTANCE OF TEMPERATURE FACTOR IN CONDUCTING
GRASSHOPPER BAIT TESTS

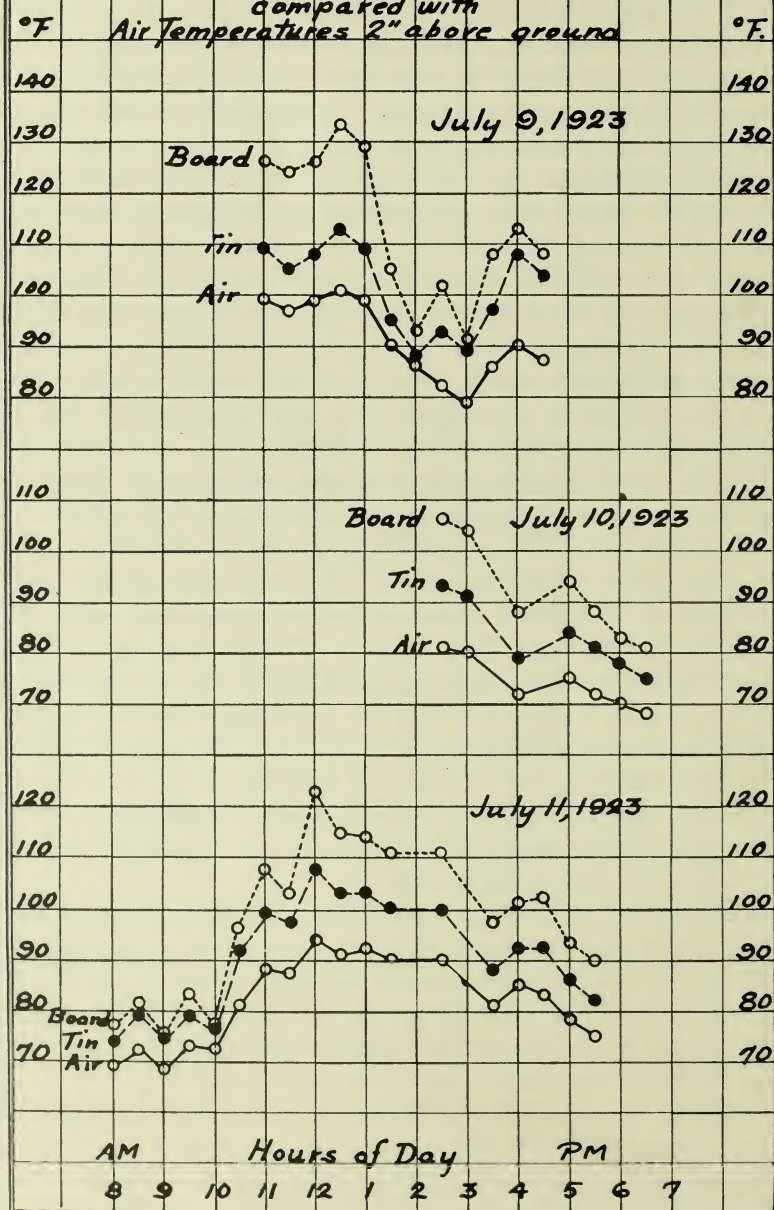
The importance of giving very careful attention to the effect of temperature upon the activity of grasshoppers was brought out strikingly in connection with the use of boards and tin pans as containers for the poisoned bran mash in the bait experiments at Harney. Shellacked or paraffined boards 12 by 12 inches, were recommended for this purpose by the Winnipeg conference. Consequently 12-inch squares of beaver board, three sixteenths of an inch thick, reddish brown in color and heavily shellacked, were prepared for the work in Minnesota and were used for several days. In watching grasshoppers on these boards from early morning until evening it soon became apparent that their activities were different from those the writer had witnessed in previous years in many days of watching grasshoppers come to baits in tin pans. During the cooler hours of the morning and in late afternoon the grasshoppers would crawl on to the boards in such numbers that it was difficult to count them or to determine whether they were feeding, while in the hottest part of the day those that ventured on the boards would rise on their tarsi and appear to be standing on their "tip-toes" in order to escape the hot surface of the boards. This led to a comparison of the temperatures on boards and tin pans which gave some rather surprising results. Mercury thermometers laid on the surface of the boards always registered higher than when placed in a similar position on bright tin pans. Temperatures were taken on both boards and pans for three days with results that are shown in the graphs in Figure 6. On hot days the temperature on the surface of the boards sometimes reached 133° F. (56° C.), the pans at the same time registering only 113° F. (45° C.), a difference of 20°; in cooler weather the difference was less striking but the temperature of the pans always more closely approached that of the air two inches above the ground than did that of the boards.

Earlier in this paper it was shown that *C. pellucida* nymphs, when given a choice, chose a surface having a temperature of approximately 98° F. (36.6° C.); that adults crawled up on grass and weeds whenever the ground temperature was 100 to 110° F. (37.7 to 43.3° C.), and that when confined in the temperature cabinet normal activities were interrupted when the temperature was above 113° F. (45° C.).

A glance at the graphs in Figure 6 shows that the surface of the bait boards was above this temperature for several hours on both July 9 and July 11, thus largely preventing feeding no matter how attractive the baits placed on the board might be. During the same time the surface of the pans was slightly below this temperature, allowing the grasshoppers to come to the baits if they so desired.

Figure 6

*Temperatures on Boards and Tins
compared with
Air Temperatures 2" above ground*



When the surface of the bait boards is cooled to 98° F. (36.6° C.) the pan will register only 88 to 90° F. (31.1 to 32.2° C.) and at this and all lower temperatures the boards will be preferred to the pans as roosting places because of the tendency of the grasshoppers always to seek warmer surfaces until the optimum of approximately 98° F. (36.6° C.) is reached. The greater attraction of the grasshoppers to the boards because of more favorable temperature would naturally bring more of them in contact with the baits and result in more feeding than if pans were used. It therefore seems that the use of boards and pans would give quite different results, the use of the former stimulating feeding during the cooler hours of the day and often checking it at high temperature; the latter attracting fewer grasshoppers because of warmth alone and seldom checking normal feeding at higher temperatures. If the relative attractiveness of the baits is the only thing to be determined, probably boards and pans would give quite similar results; but if it is also desired to find out the hours of maximum feeding the use of boards would introduce a very serious error and might lead to erroneous conclusions as to the correct time and temperature at which poisoned bran mash should be distributed.

EFFECT OF WIND

Hourly records of the wind velocity at Harney were made from July 8 to July 14, but it was so uniformly low that no conclusions can be drawn as to its effects on grasshopper activities. The highest velocity recorded was only 6.9 miles per hour, which had no apparent effect in checking normal activities. The writer has observed in previous years that *C. pellucida* feeds and moves about but little on extremely windy days, but the exact velocity necessary to retard activities was never determined.

In watching flights of *C. pellucida* in Montana, it was often noted that a breeze just strong enough to ripple tall grass or standing grain would stimulate flying, while absolute calmness or a strong wind had the opposite effect.

EFFECT OF MOISTURE

Altho a record of relative humidity was kept throughout the field work at Harney and is included in the data given in the tables in this paper, the writer has been unable to come to any definite conclusion as to how it affects the daily activities of *C. pellucida*. Grasshoppers fed in greater numbers and seemed to seek the baits more eagerly on June 29 and 30 and July 2 than on any other days, and it so happened that on these days the relative humidity was lower than at any other time during the experiment. It is more than likely that the low humidity

stimulated feeding somewhat, but the fact that the grasshoppers were then immature, more densely massed, and less easily disturbed than was the case later, are more definite reasons for the large numbers recorded at baits on those days. After the grasshoppers had become adult the writer was distinctly impressed with the feeling that they were not coming to baits as freely as does the same species in Montana, and the higher relative humidity that prevailed in Minnesota seemed to offer about the only reason for the difference. Since there are no data on which to base such a statement it can be looked upon as little more than a guess.

That moisture has a most important effect upon grasshoppers by causing disease to start among them is a well-known fact and was very strikingly illustrated at Harney from July 3 to July 7. The weather was rainy or foggy during the entire period with the relative humidity seldom below 98 per cent. After three days of this weather it was noticed that a few grasshoppers were dying of what appeared to be a bacterial disease, and on the fourth day great numbers were affected and their bodies could be seen everywhere attached to weeds and grass upon which they climbed while in the last stages of the disease. On the fifth day the air cleared and the several days of bright sunshine which followed completely checked the disease which threatened the entire grasshopper population had the wet weather continued much longer. Similar epidemics of disease among grasshoppers have been witnessed during periods of wet weather in Montana, and there can be little question that excessive moisture acting as a promoter of fungous and bacterial diseases is one of the biggest natural checks with which *C. pellucida* has to contend.

III. MISCELLANEOUS NOTES ON SEASONAL HISTORY AND HABITS

SEASONAL HISTORY FOR 1923

As little has been published on the seasonal history of *C. pellucida* in Minnesota, it seems desirable to record here the data gathered in 1923. When the infested area at Harney was first visited on June 21, the majority of the grasshoppers were in the second and third instar, altho many were still in the first stage. On June 28 nearly all were in the fourth and fifth instars and by July 3 many adults were appearing. On July 8 nearly all had acquired wings and some mating was taking place. The first egg-laying was noticed on July 14, but only one ovipositing female was seen on that date. Mating, however, was in full swing. When the infestation was visited again on July 28, egg-laying was in full progress and according to local observers continued throughout August.

DIFFERENCE IN HABITS UNDER VARIED ENVIRONMENT

Several rather striking differences were noticed in the habits of *C. pellucida* in the infestation at Harney as compared with those of the same species in Montana. In the latter state the young hatch in great numbers in restricted areas and after a varying number of days begin to migrate, marching together in bands and thus earning the name "warrior grasshopper." In the infestation at Harney, altho the young hatched in great numbers no migration was witnessed, the grasshoppers growing to maturity within a few rods of where they hatched.

The adults also showed little tendency to migrate, flying only very short distances, with the result that mating and egg-laying took place in the same areas where the eggs had been deposited the previous year. This is very different from the habits of the adults in Montana and in Utah as reported by Ball (1915). In those states certain favorable spots are selected for mating and egg-laying, adults flying for considerable distances to reach them.

In such areas the males always predominate, apparently remaining on the breeding ground after they have once arrived while the females lay one pod of eggs and then fly away, returning for a second and possibly a third oviposition as the eggs mature. The result is that the eggs are concentrated in great numbers in a few spots, the ground sometimes appearing to be literally full of them. At Harney the eggs were widely distributed over the whole infested area and could be found only by considerable searching.

One explanation of this apparent change of habit may be that in the cut-over pastures where *C. pellucida* is most commonly found in Minnesota, dry soddy knolls and hummocks are everywhere abundant, offering ideal egg laying grounds which are only a few feet from the lower and damper ground where green vegetation is available. Favorable breeding and feeding grounds occurring side by side, there is no need for migrations of either young or adults.

SUMMARY

1. Amyl acetate was the most effective of several materials used as attractants in grasshopper baits, surpassing butyl and propyl acetate, lemons, and synthetic apple flavoring.

2. All attractants except lemons gave better results when used in combination with molasses.

3. Salt not only added to the effectiveness of all attractants with which it was combined but in some tests ranked very high when used alone.

4. Grasshopper baits for use in Minnesota should contain amyl acetate, molasses, and salt, in addition to the basic ingredients—bran, arsenic, and water.

5. The activities of *C. pellucida* are to a large extent controlled by temperature. The range of normal activity extends from approximately 68 to 104° F. (20 to 40° C.). Little movement is seen at air temperatures below 60° F. (15.5° C.) and several hours' exposure at 40° F. (5° C.) renders it completely dormant. Fatal temperatures for a 12-hour exposure are reached at 17.6° F. (−8° C.). Fatal high temperatures for 10-minute exposures occur at 122 to 136° F. (50 to 57.7° C.) several specimens surviving the latter temperature, however.

6. When given a choice, *C. pellucida* prefers to rest on surfaces whose temperatures approximate 98 to 100° F. (36.6 to 37.7° C.). The surface of the ground frequently is much warmer than this but the grasshopper can generally reach a temperature it prefers by simply climbing up weeds or grass to two inches above the ground, this sometimes making a difference of 39.6° F.

7. Maximum feeding at poisoned bran mash occurs when the air temperature first reaches from 73 to 77° F. (22.7 to 25° C.).

8. A comparison of tin pans and boards for containers of poisoned bran mash in conducting grasshopper bait tests showed that the surface of the boards was much warmer than the surface of the pans. This caused the grasshoppers to seek the boards for warmth during the cooler hours of the day and to avoid them during the hottest hours, thus introducing a serious experimental error.

9. Continued high relative humidity is detrimental to *C. pellucida*, as it brings about conditions favorable for the development of grasshopper diseases.

10. In Minnesota, *C. pellucida* nymphs did not migrate and no congregating of the adults in definite areas for egg laying were witnessed. This is in marked contrast to the habits of the same species in Montana and Utah where migrations of the young nearly always take place and the adults gather over a considerable area in a few places for mating and egg laying.

BIBLIOGRAPHY

- Ball, E. D. How to control the grasshoppers. Utah Agr. College Exp. Sta. Bul. 138. 1915.
- Nikolsky. Reasons for the migration of the larvae of the Asiatic locust. Separate from Turkestan Agriculturist, Tashkent, 1918, Nos. 3 and 4. 1918.
- Somes, M. P. The Acrididae of Minnesota. Minn. Agr. Exp. Sta. Bul. 141. 1914. (Out of print.)
- Swenk, M. J. Experiments with poisoned baits for grasshoppers. Nebraska Agr. Exp. Sta. Bul. 183. 1923.
- Uvarov, B. P. Some problems of the biology of the grasshopper. Annales des Epiphytes, Vol. IX, No. 2, p. 87. 1923.